Title: Quantum Universe

Date: Jun 07, 2016 04:00 PM

URL: http://pirsa.org/16060002

Abstract:

Quantum Universe

1 Observations : 6 numbers = 4 + 2

densities geometry

$$H = \frac{\dot{a}}{a} \qquad a(t)$$

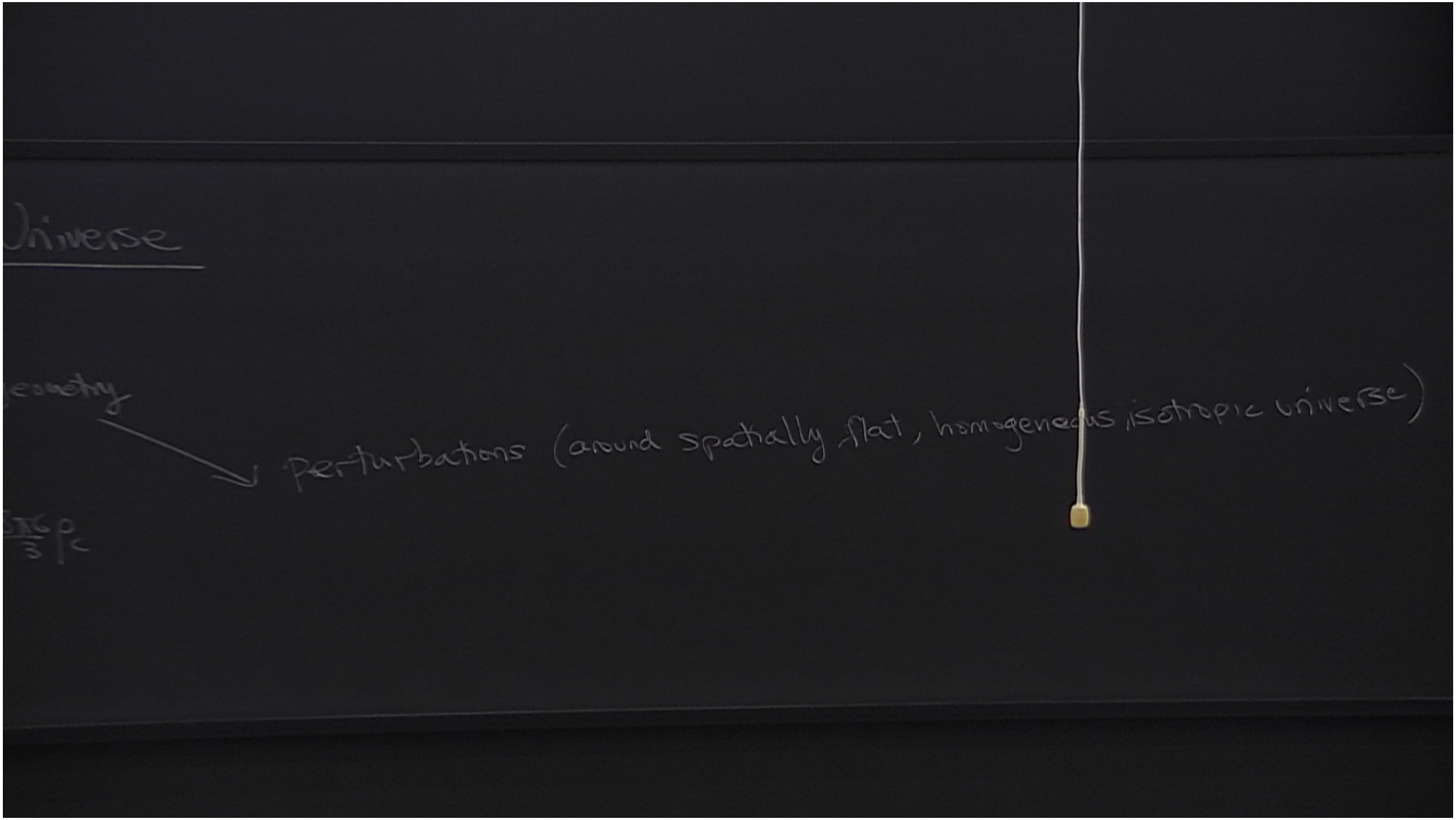
$$H^2 = \frac{8\pi G}{3}\left(\rho_\gamma + \rho_B + \rho_{DM} + \rho_\Lambda\right) \equiv \frac{8\pi G}{3}\rho_c$$

$\rho_\gamma \simeq 0.00005\,\rho_c$

$\rho_B \simeq 0.05\,\rho_c$

$\rho_{DM} \simeq 0.25\,\rho_c$

$\rho_\Lambda \simeq 0.7\,\rho_c$


Universe
Geometry
perturbations (around spatially flat, homogeneous, isotropic universe)

Universe

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$\frac{3H^2}{8\pi G}\rho_c$

⇒ power spectrum $A_s k^{n_s}$

$A_s \simeq 3 \times 10^{-10}$

$n_s \simeq 0.97$ (1 would be classical scale invariance)

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$\rho_{DM} \simeq 0.25\,\rho_c$ $\quad \rho_\Lambda \simeq 0.7\,\rho_c$

$\langle \delta\delta \rangle$

$\Rightarrow$ power spectrum $\quad A_s\, k^{\;}$

$A_s \simeq 3\times 10^{-10}$

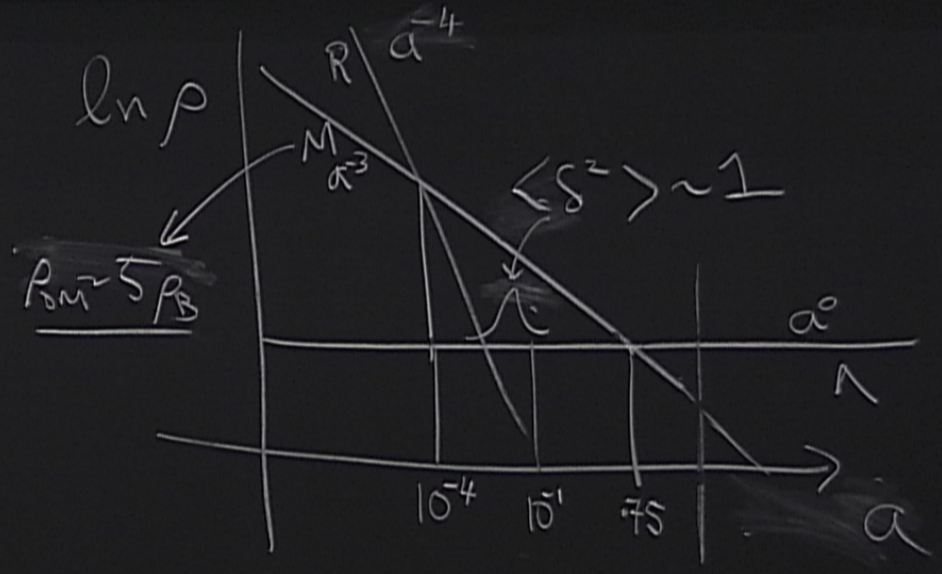
$n_s \simeq 0.97$ (1 would be cla

Many zeros: mean Spatial Curvature, tensor pert^{ns} $\left(\frac{A_T}{A_S}\right) < 0.07$, $\left|1 + \frac{p_\Lambda}{\rho_\Lambda}\right| \lesssim 0.1$, $\frac{dn_s}{d\ln k}$,

Nongaussianity $\left|\frac{\langle \delta^3 \rangle}{\langle \delta^2 \rangle^{3/2}}\right| \lesssim 10^{-2}$

Coincidences

1)



2) $\rho_\Lambda \sim 10^{-120} M_{Pl}^4$

SM < 90 fermions, 30 bosons } $\langle T_{00} \rangle = -\Lambda^4$

3) Clue from LHC



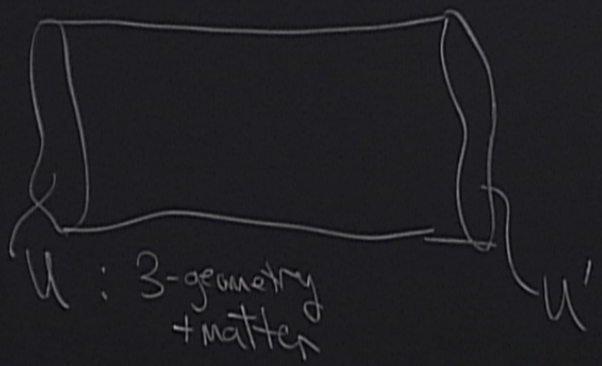
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3) Clue from LHC



Quantum Cosmology



= propagator $\langle U|U' \rangle$

S. Gielen

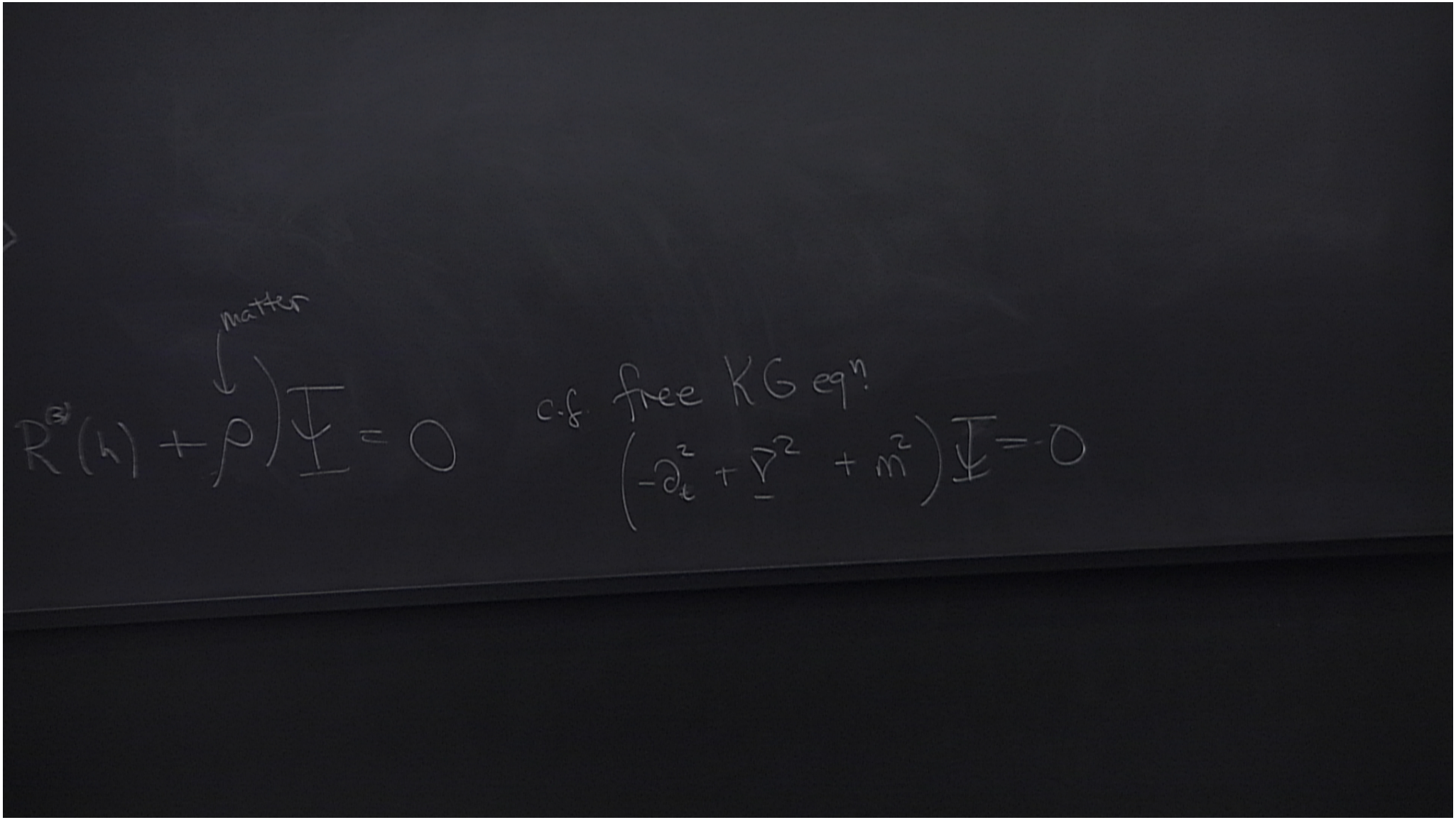
Hamiltonian

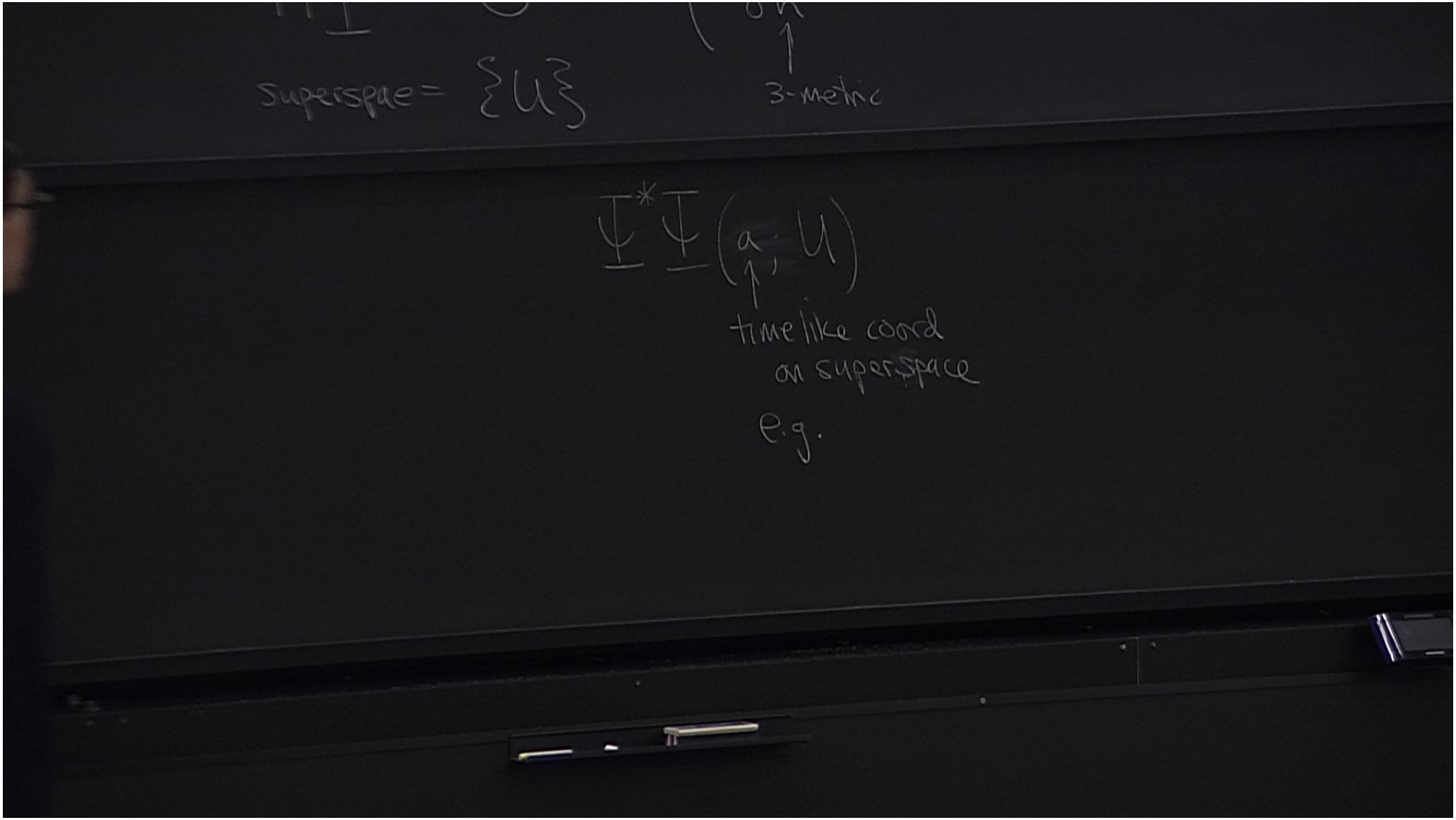
$$\hat{H}\Psi = 0$$

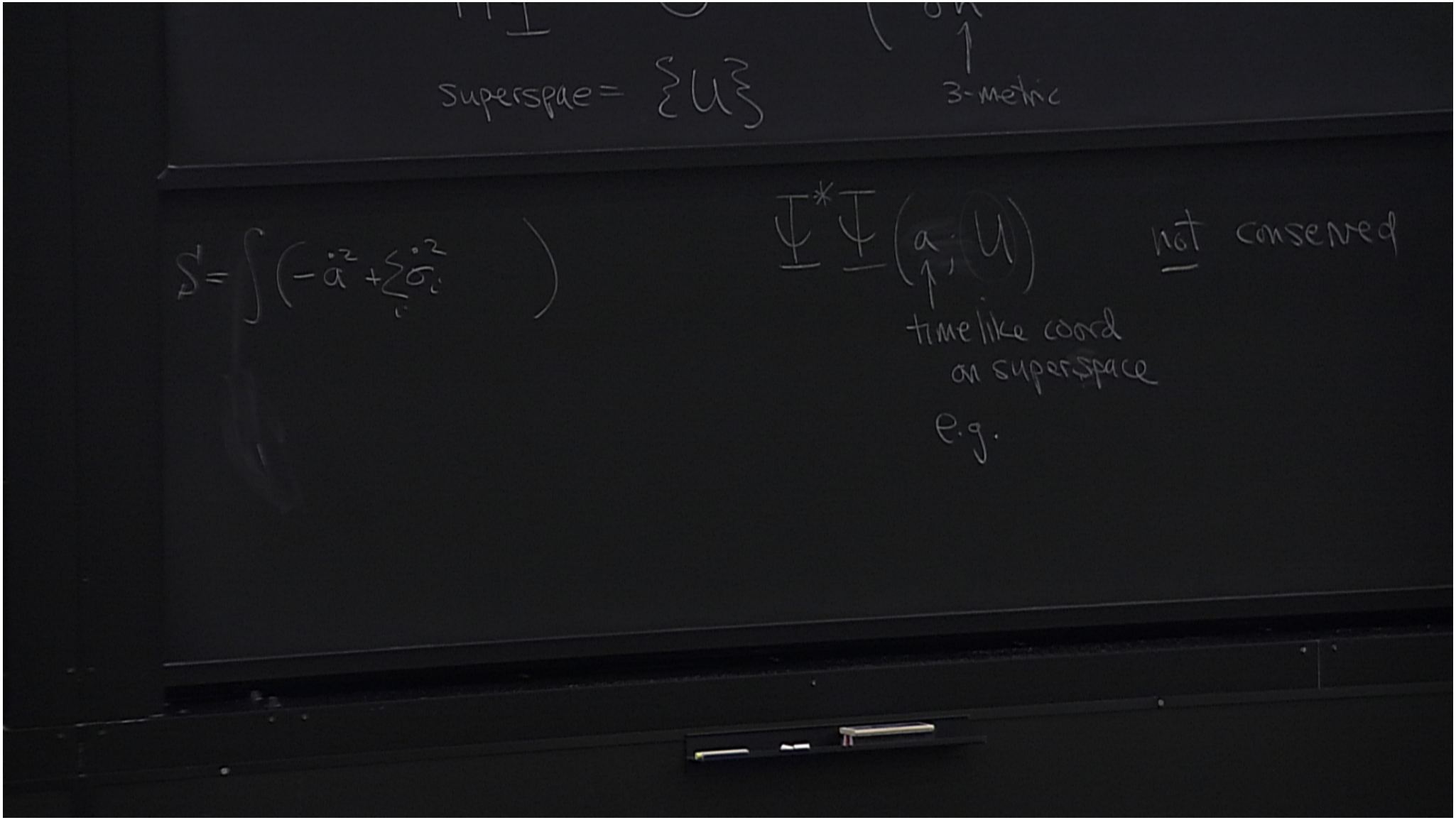
$$\left(\frac{\delta^2}{\delta h^2} + R^{(3)}(h) + \rho \right) \Psi = 0$$

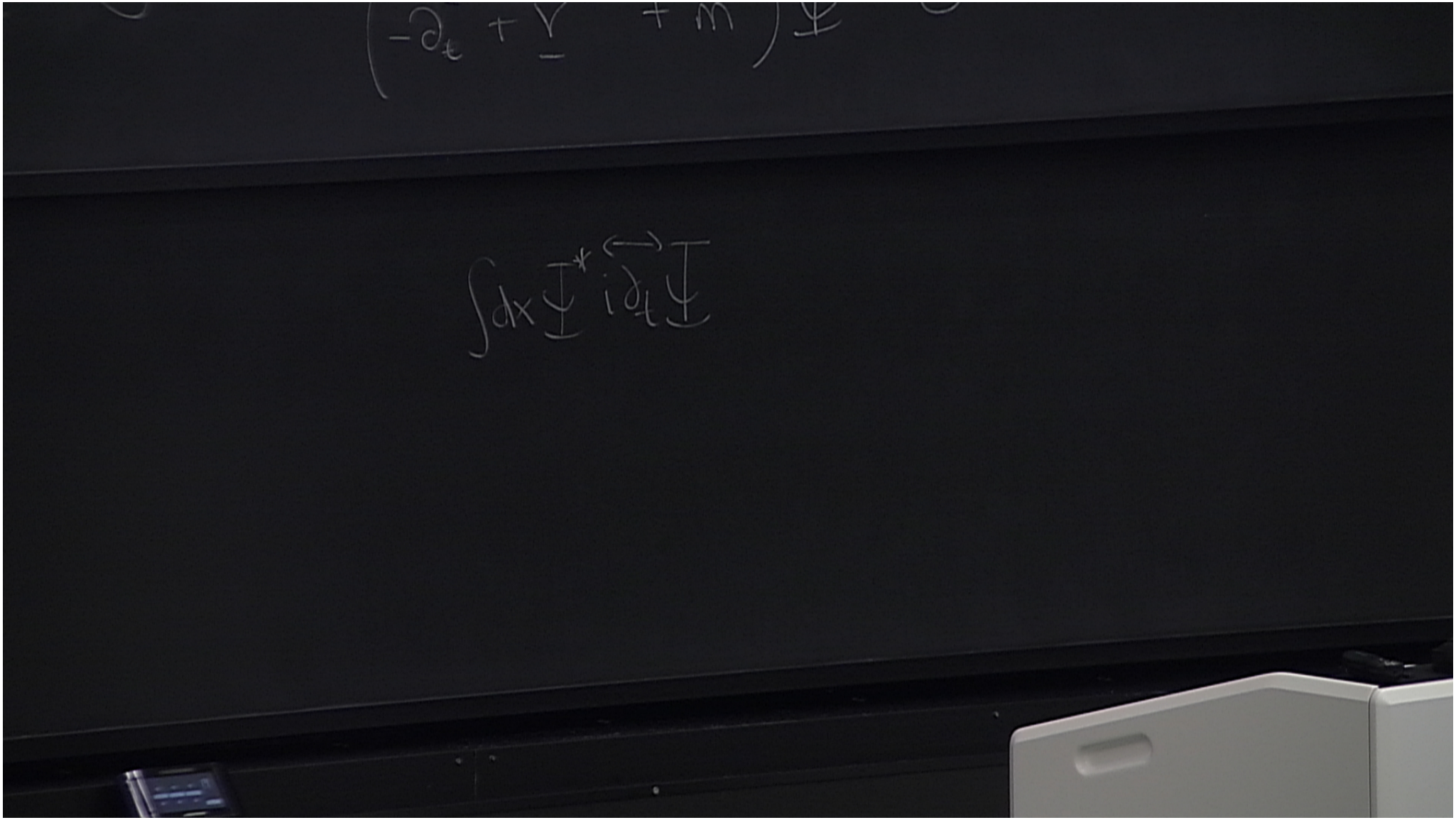
ρ: matter

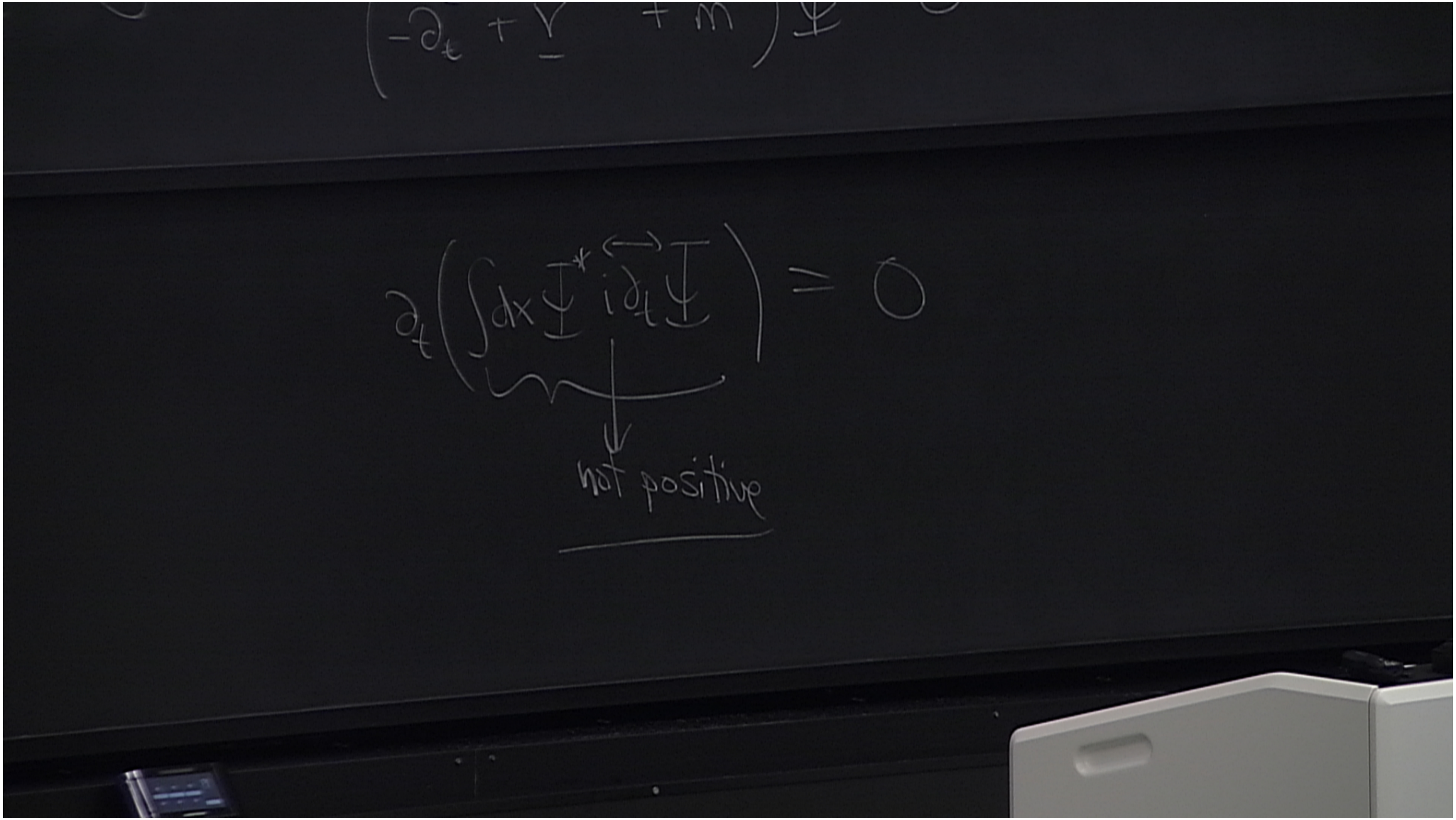
h: 3-metric

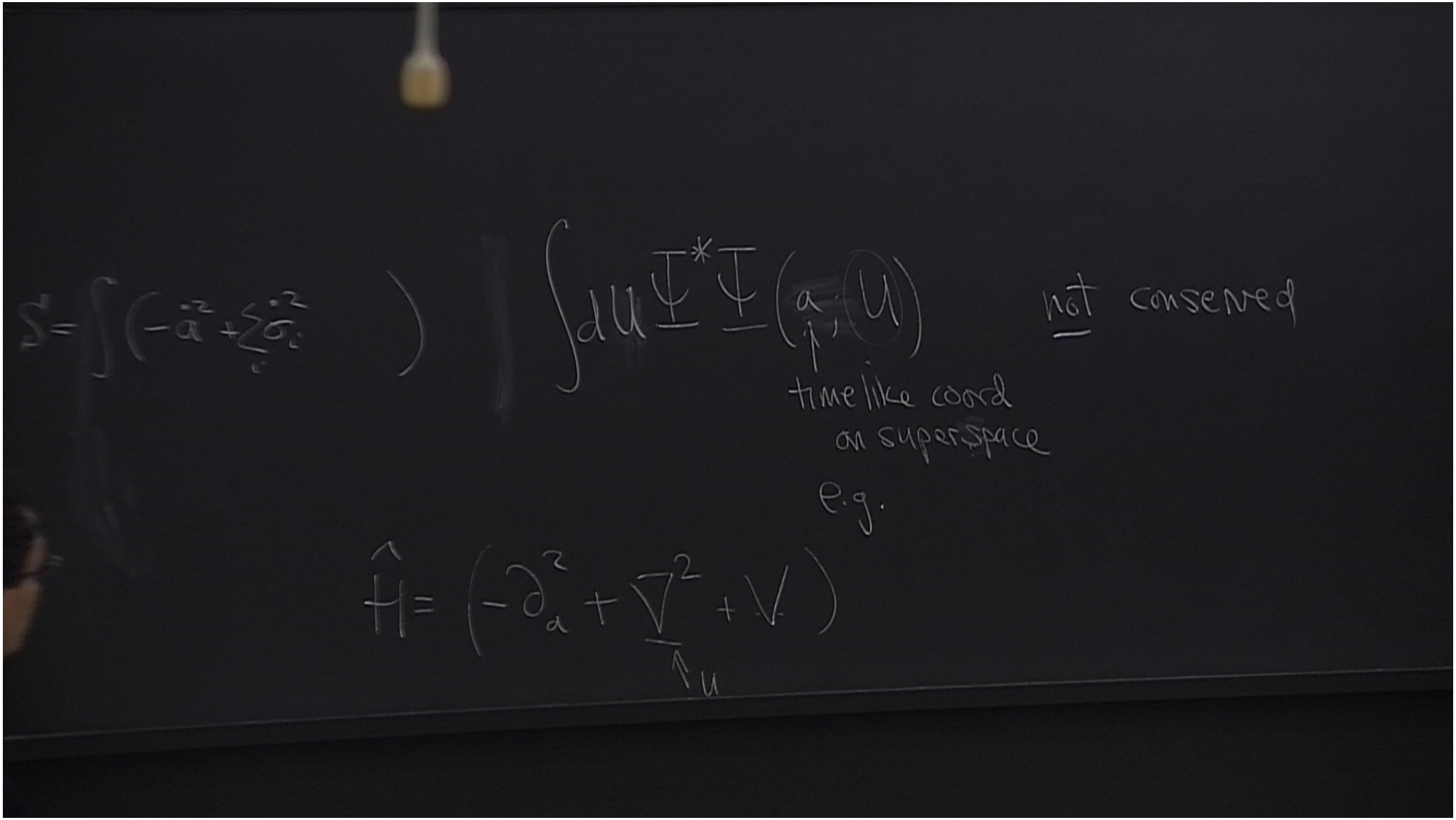

matter
$R^{(3)} + \rho \underline{\Psi} = 0$
c.f. free KG eqn
$\left(-\partial_t^2 + \underline{\nabla}^2 + m^2\right)\underline{\Psi} = 0$


Superspace = {q}
3-metric
Ψ* Ψ (α; q)
time like coord on superspace
e.g.


Superspace = {α, β}
3-metric
$S = \int \left(-\dot{a}^2 + \sum_i \dot{\sigma}_i^2 \right)$
$\Psi^* \Psi (a, \alpha, \beta)$
not conserved
time like coord on superspace
e.g.


$\left(-\partial_t + \underline{V} + m\right)\underline{\psi}$
$\int dx\, \underline{\psi}^* \overleftrightarrow{i\partial_t} \underline{\psi}$


$\partial_t \left(\int dx \, \Psi^* \overleftrightarrow{i\partial_t} \Psi \right) = 0$
not positive


$S = \int \left(-\dot{a}^2 + \sum_i \dot{\sigma}_i^2 \right)$
$\int du \, \Psi^* \Psi \left(\begin{matrix} a \\ \sigma_i \end{matrix}, u \right)$
not conserved
time like coord on superspace
e.g.
$\hat{H} = \left(-\partial_a^2 + \nabla^2 + V \right)$
$\uparrow u$

$\int(-\ddot{a}^2 + \sum_i \dot{\sigma}_i^2)$ $\int dU \Psi^* \Psi(a, U)$ not conserved

time like coord on superspace

e.g.

$\hat{H} = (-\partial_a^2 + \nabla^2 + V)$

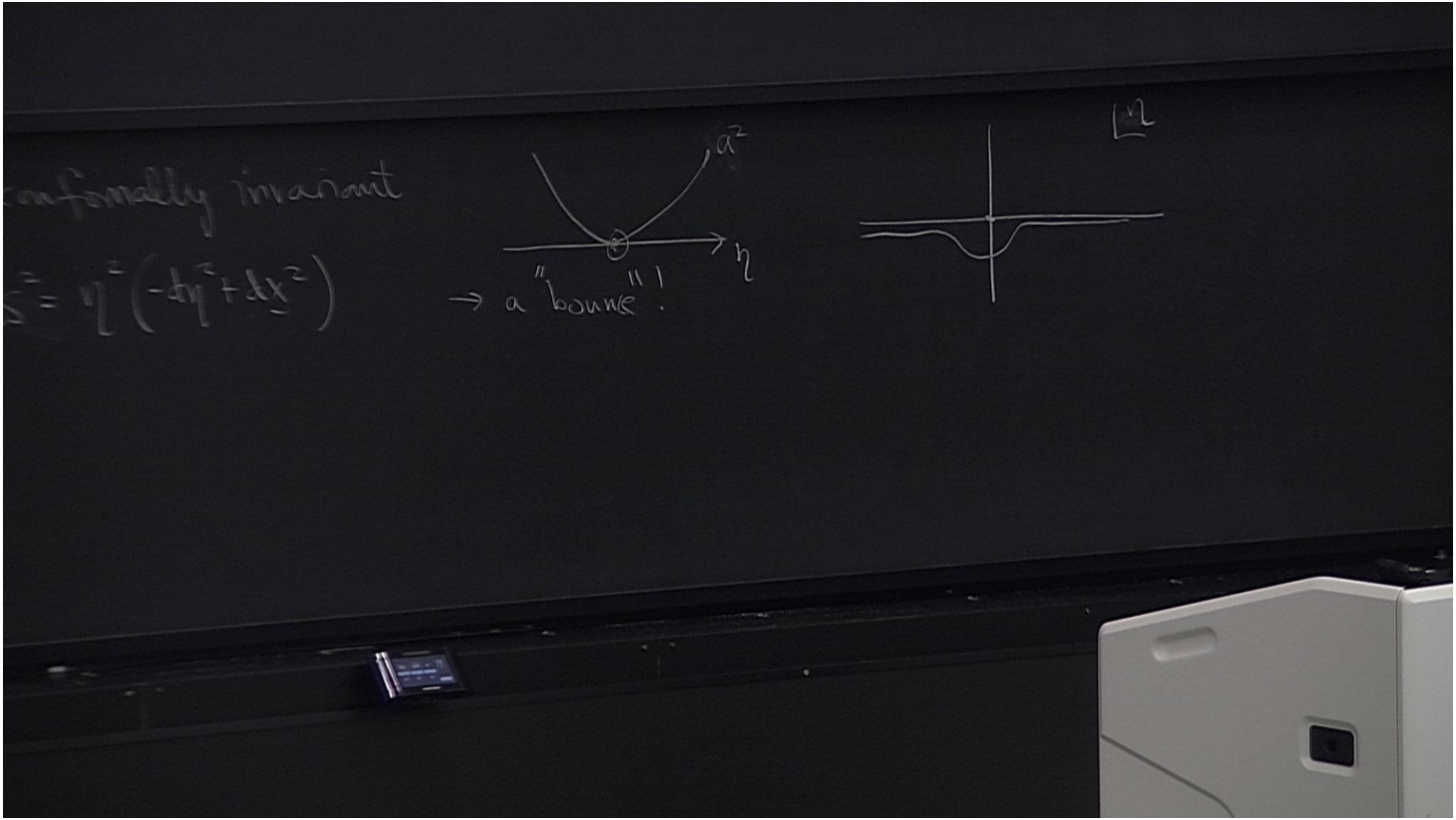
$\uparrow_U$

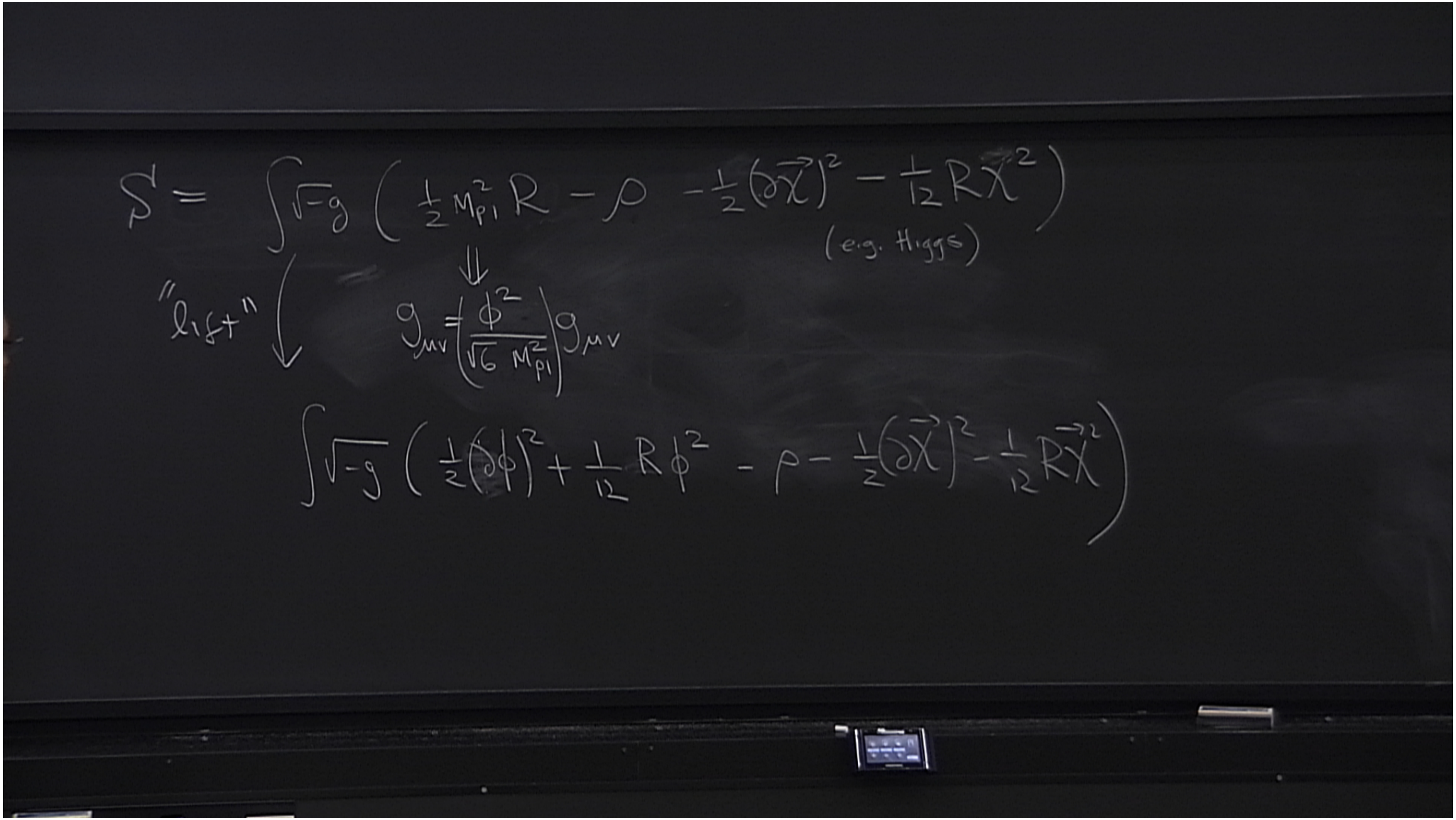
$H = \left(-\partial_a + \nabla^2 + V\right)$

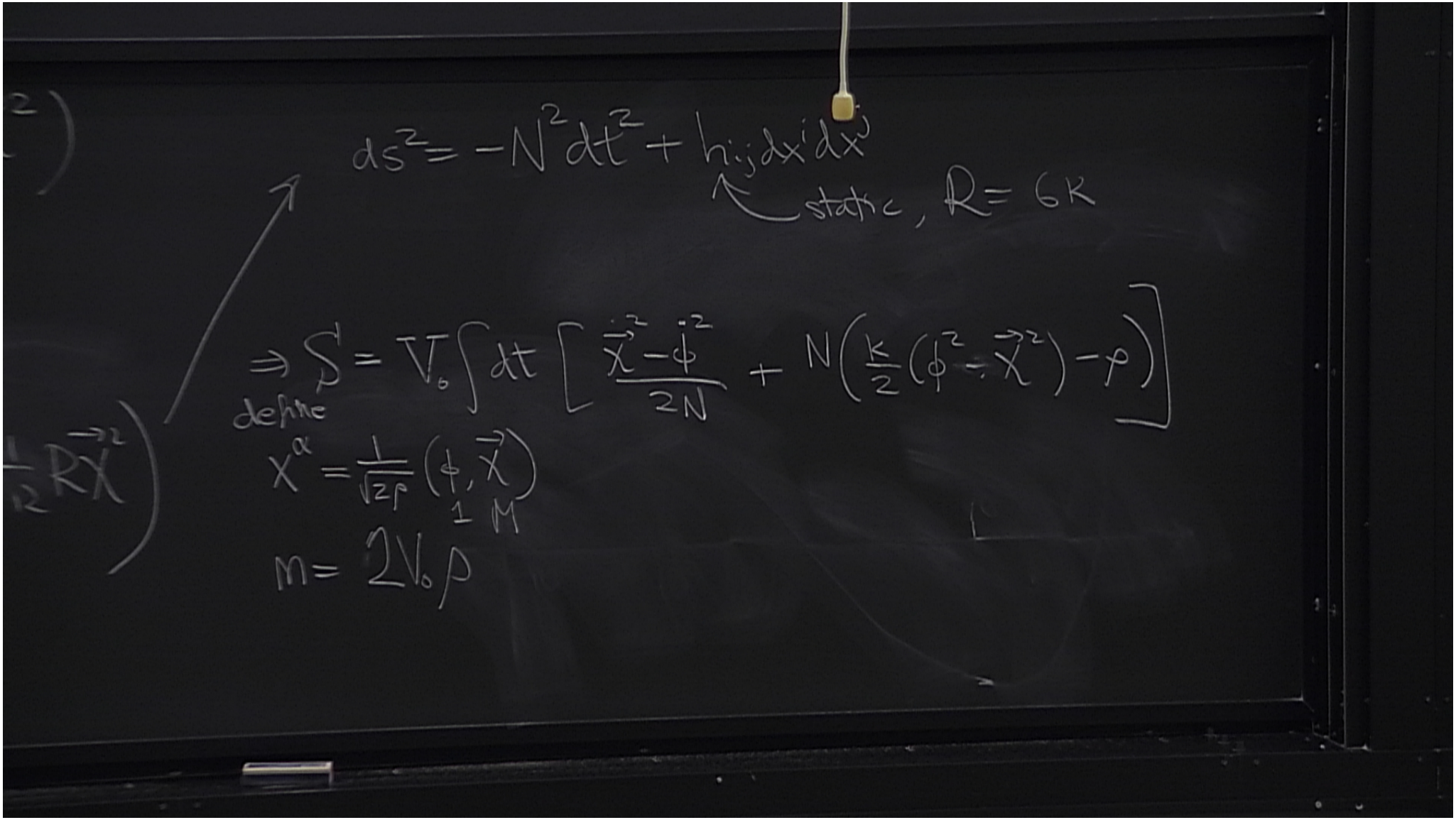
$\uparrow u$

Simplest case — matter which is conformally invariant

e.g. flat, ~~FRW~~ RDU $\quad ds^2 = \eta^2\left(-d\eta^2 + d\underline{x}^2\right)$


conformally invariant
$ds^2 = \eta^2(-d\eta^2 + dx^2)$
a^2
η
→ a "bounce"!
$\ln \eta$


$S = \int \sqrt{-g}\left(\frac{1}{2}M_{Pl}^2 R - \rho - \frac{1}{2}(\partial\vec{\chi})^2 - \frac{1}{12}R\vec{\chi}^2\right)$
(e.g. Higgs)
"first"
$g_{\mu\nu} = \left(\frac{\phi^2}{\sqrt{6}\,M_{Pl}^2}\right) g_{\mu\nu}$
$\int \sqrt{-g}\left(\frac{1}{2}(\partial\phi)^2 + \frac{1}{12}R\phi^2 - \rho - \frac{1}{2}(\partial\vec{\chi})^2 - \frac{1}{12}R\vec{\chi}^2\right)$


$ds^2 = -N^2 dt^2 + h_{ij} dx^i dx^j$
static, $R = 6K$
$\Rightarrow S = V_0 \int dt \left[\frac{\vec{x}^2 - \dot{\phi}^2}{2N} + N\left(\frac{K}{2}(\phi^2 - \vec{x}^2) - \rho\right) \right]$
define
$X^\alpha = \frac{1}{\sqrt{2\rho}}(\phi, \vec{x})$
1 M
$m = 2V_0\rho$

$\frac{1}{12}R\dot{\vec{X}}^2$)

...ggs)

$ds^2 = -N^2dt^2 + h_{ij}dx^i dx^j$

static, $R = 6K$

$\vec{X}|^2 - \frac{1}{12}R\vec{X}^2$)

$\Rightarrow S = V_0 \int dt \left[\frac{\dot{\vec{X}}^2 - \dot{\phi}^2}{2N} + N\left(\frac{K}{2}(\phi^2 - \vec{X}^2) - \rho\right)\right]$

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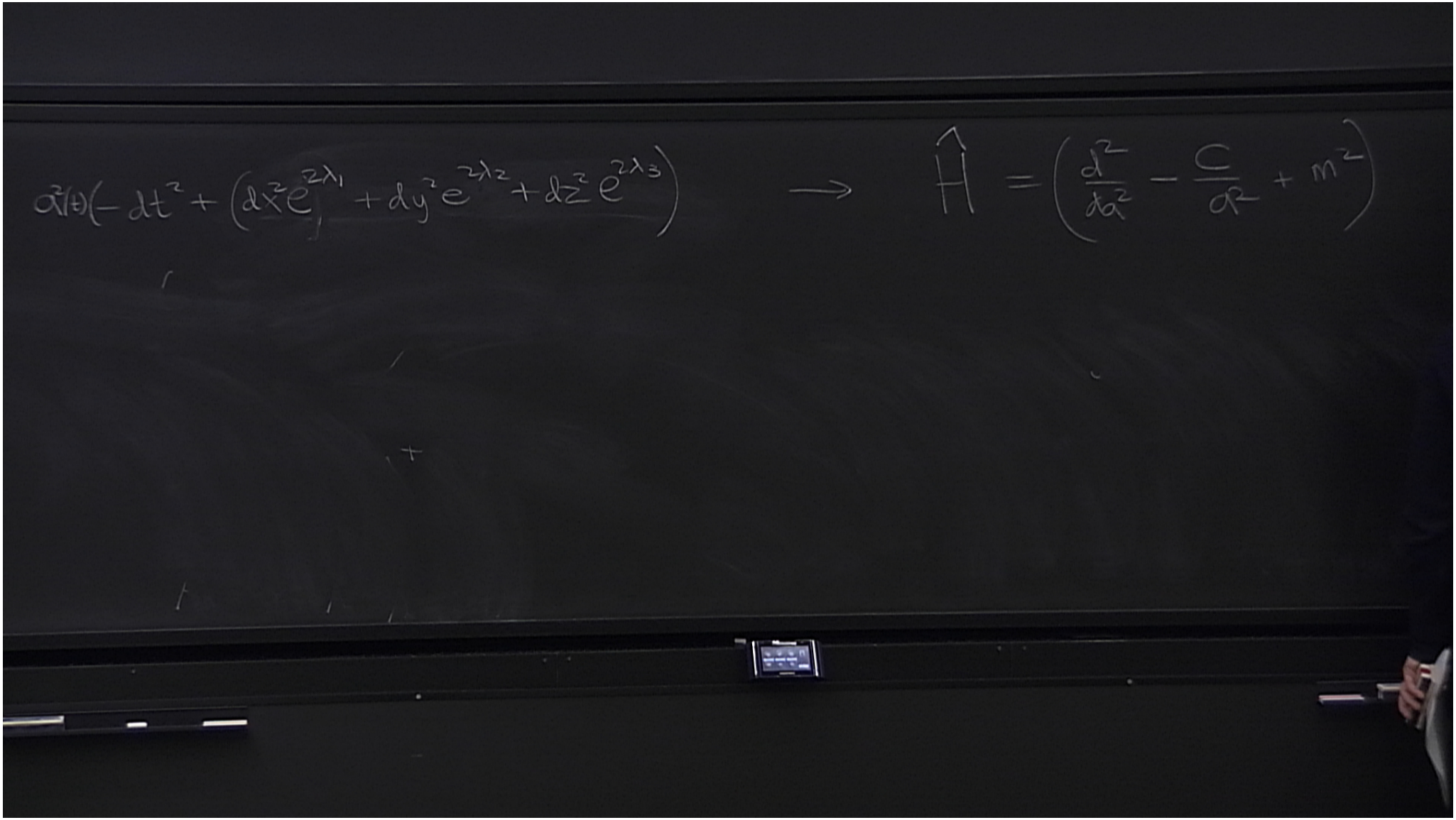
$1 \quad M$

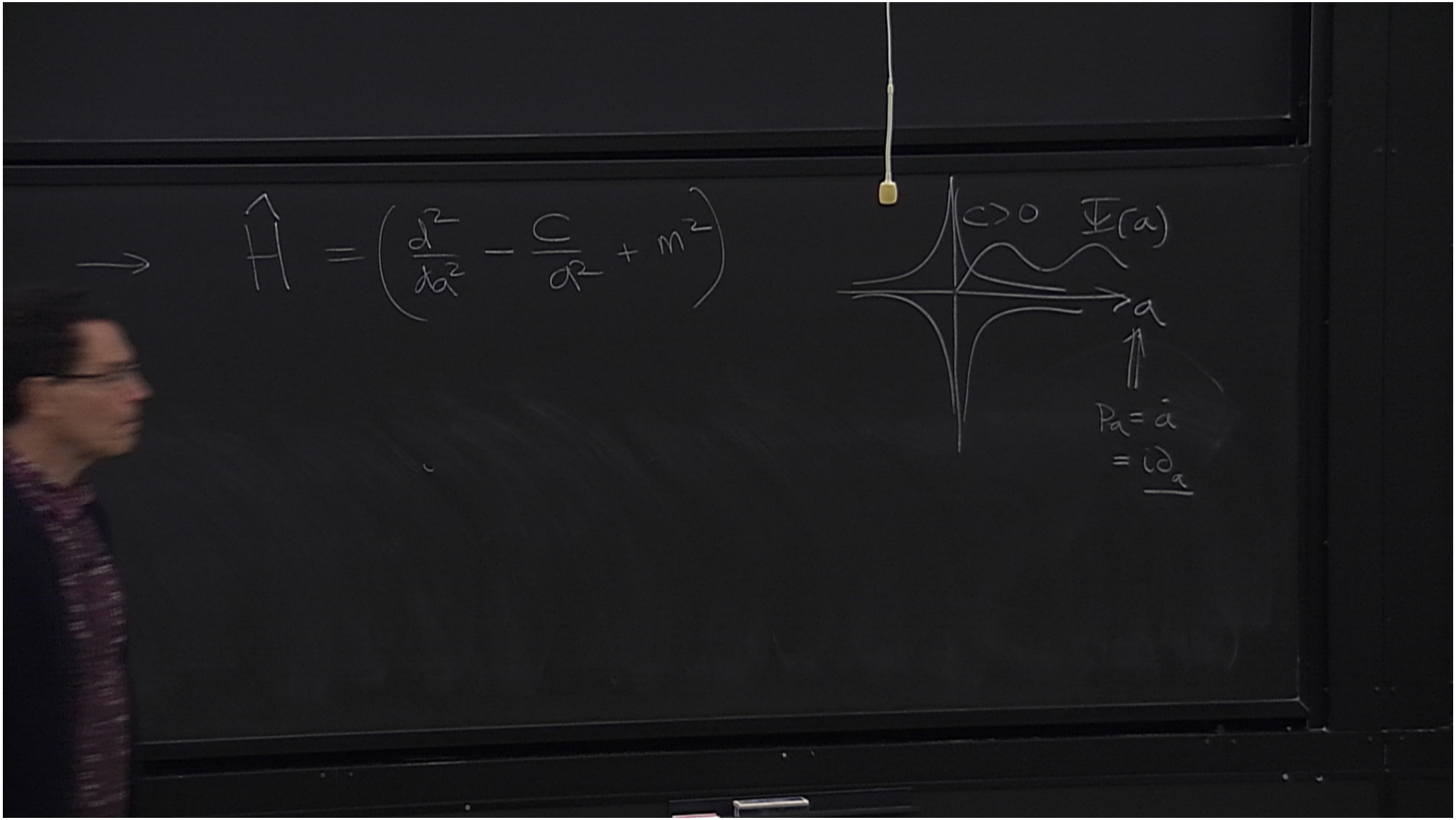
$m = 2V_0\rho$

$\Rightarrow S = \frac{m}{2}\int \left(\frac{1}{N}\dot{X}^\alpha \dot{X}_\alpha - N\left(1 + KX^\alpha X_\alpha\right)\right)$

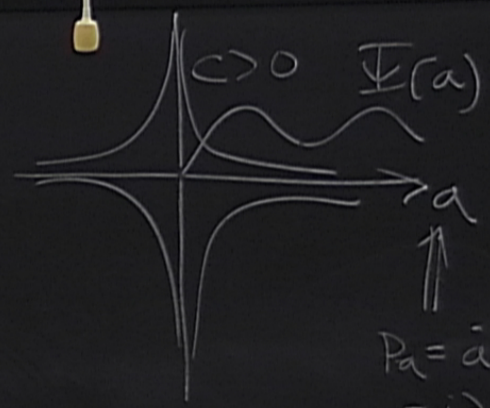
static.

< 0.07, $\left|1 + \frac{P_\Delta}{\ldots}\right| < 0.1$ $\frac{dn_s}{\ldots}$,

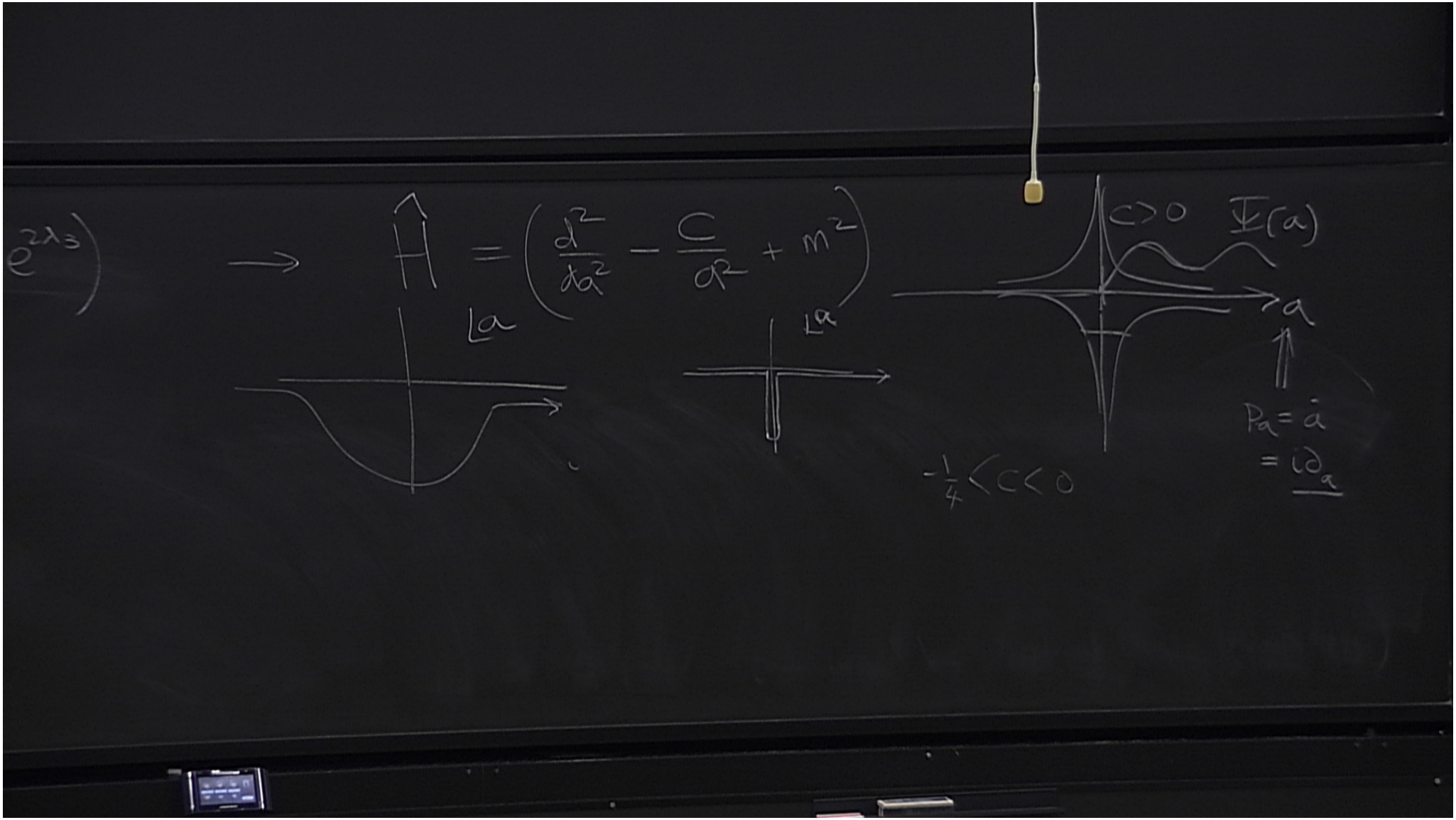

$a^2(\eta)\left(-d\eta^2 + \left(dx^2 e^{2\lambda_1} + dy^2 e^{2\lambda_2} + dz^2 e^{2\lambda_3}\right)\right) \longrightarrow \hat{H} = \left(\frac{d^2}{da^2} - \frac{c}{a^2} + m^2\right)$


$\hat{H} = \left(\frac{d^2}{da^2} - \frac{c}{a^2} + m^2\right)$
$c > 0$
$V(a)$
a
$P_a = \dot{a}$
$= i\partial_a$

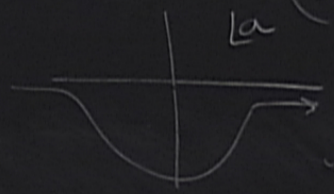
$$\rightarrow \quad \hat{H} = \left(\frac{d^2}{da^2} - \frac{C}{a^2} + m^2 \right)$$

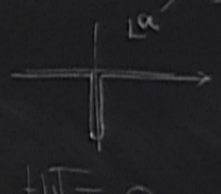


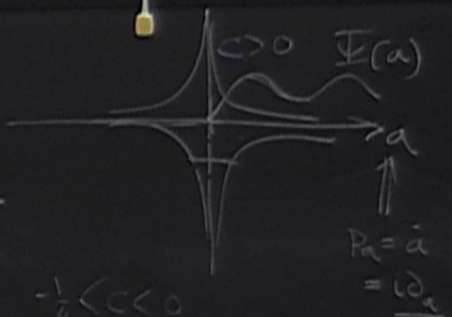
$$P_a = \dot{a} = i\partial_a$$


$e^{2\lambda_3}$
$\hat{H} = \left(\frac{d^2}{da^2} - \frac{c}{a^2} + m^2\right)$
La
La
c>0
$\Psi(a)$
a
$P_a = \dot{a}$
$= \omega_a$
$-\frac{1}{4} < c < 0$

$a^2(\eta)\left(-d\eta^2 + \left(dx^2 e^{2\lambda_1} + dy^2 e^{2\lambda_2} + dz^2 e^{2\lambda_3}\right)\right) \longrightarrow \hat{H} = \left(\frac{d^2}{da^2} - \frac{c}{a^2} + m^2\right)$







$\rightarrow G(a,u|a',u')$

$+\frac{1}{4} = 0 \qquad -\frac{1}{4} < c < 0$

Proposal: $\Psi(a,u) \quad \Psi(-a,u) \quad P_\Psi = \iint_{u\,a} \Psi^*(a,u)\, i\overleftrightarrow{\partial}_u\, G(a,u|a',u')\, i\overleftrightarrow{\partial}_{u'}\, \Psi(a',u') > 0$

G_+

$$\hat{H} = \left(-\partial_a^2 + \nabla^2 + V\right)$$

$\nabla^2 \to u$

Simplest case

matter which is conformally invariant

$$\int \left(-\dot{\phi}^2 + \dot{\chi}^2\right)$$

$$\int \left(-\dot{a}^2 + a^2\dot{\sigma}^2\right)$$

e.g. flat, FRW
RDU

$$ds^2 = a^2(\eta)\left(-d\eta^2 + d\underline{x}^2\right) \to a''$$

$$R = T = 0$$

$$R \sim \frac{\ddot{a}}{a^2}$$

$$a^2\dot{\sigma} = p_\sigma = \text{const}$$

$$H = -p_a^2 + \frac{p_\sigma^2}{a^2}$$